Remote Sensing of Ice Clouds with SWIRP

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Motivation for SWIRP (Submm-Wave and IR Polarimeter): Cloud Ice and Radiation

- Cloud ice is a major source of uncertainties in climate models;
- Cloud ice is a tuning parameter to balance radiation at top and precipitation at bottom;
- Cloud ice varies by four orders of magnitude with a strong diurnal cycle.

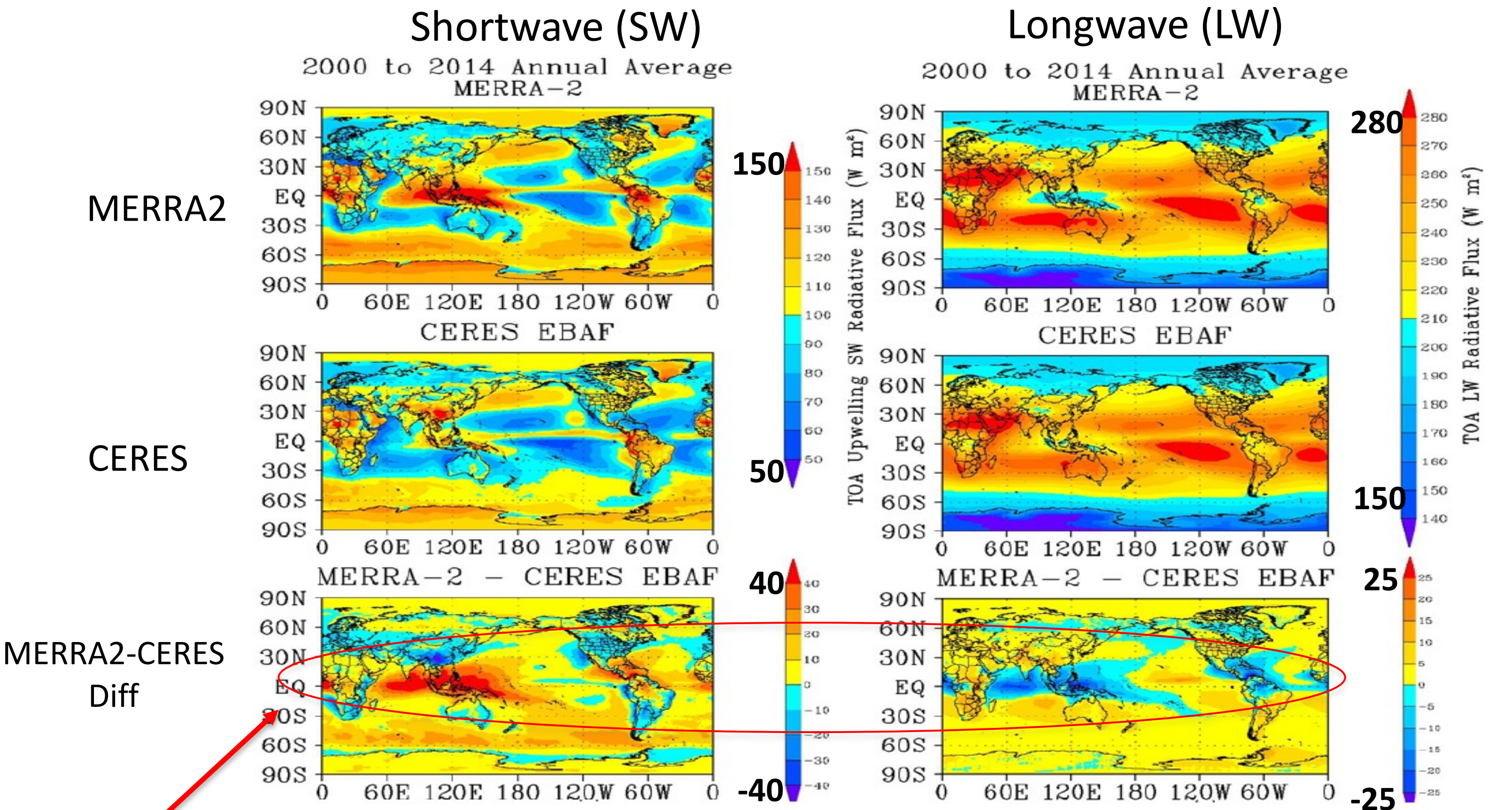


Figure 4-4 Comparing MERRA-2 (top row) to CERES EBAF (middle row) and their difference field (bottom row) for TOA outgoing longwave radiation (right) and TOA reflected shortwave radiation (left). Units are Wm^{-2}.

Bosilovich et al. (2015)

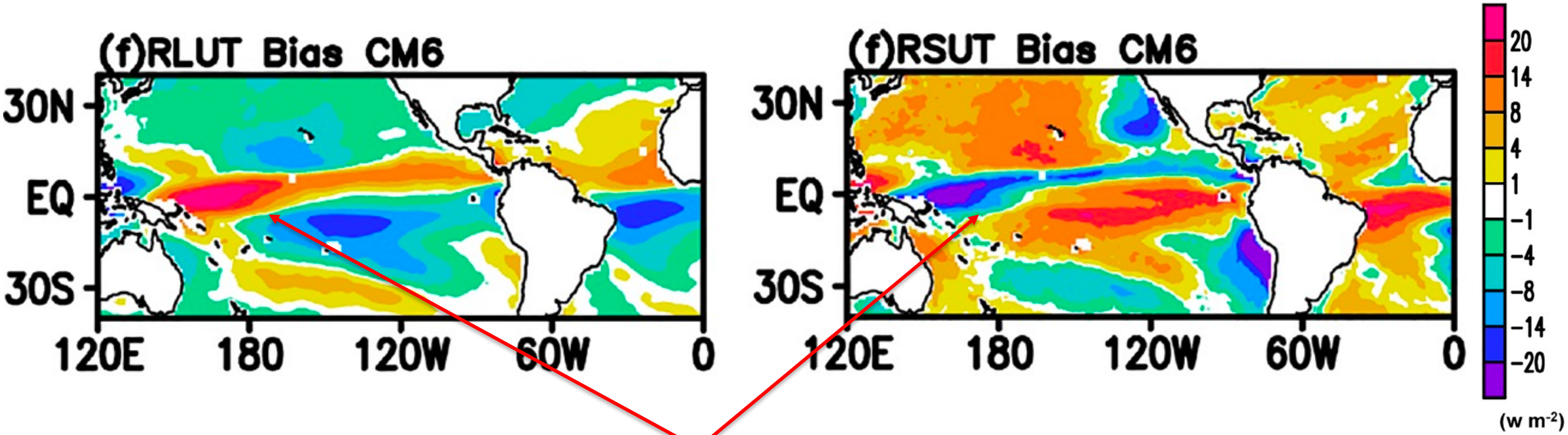
LW and SW biases are opposite and cancelled out in the net TOA radiation by wrong reasons (Ice clouds)

TOA Radiation Bias of Reanalysis vs CERES

TOA Radiation Bias in Climate Models

TOA Longwave (LW) Bias

TOA Shortwave (SW) Bias



LW and SW biases are opposite and cancelled in the net radiation by wrong reasons (Ice clouds)

Li et al. (2020)

TOA Radiation Bias of CMIP6 Models vs CERES

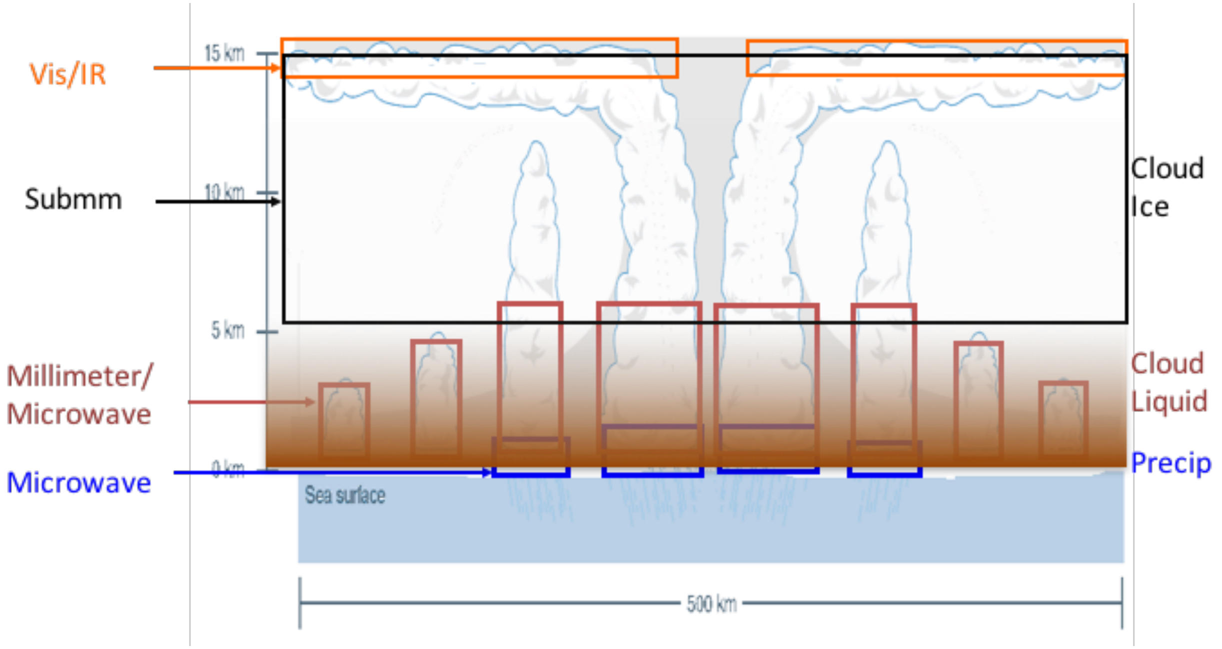
Observation Limitations and Gaps

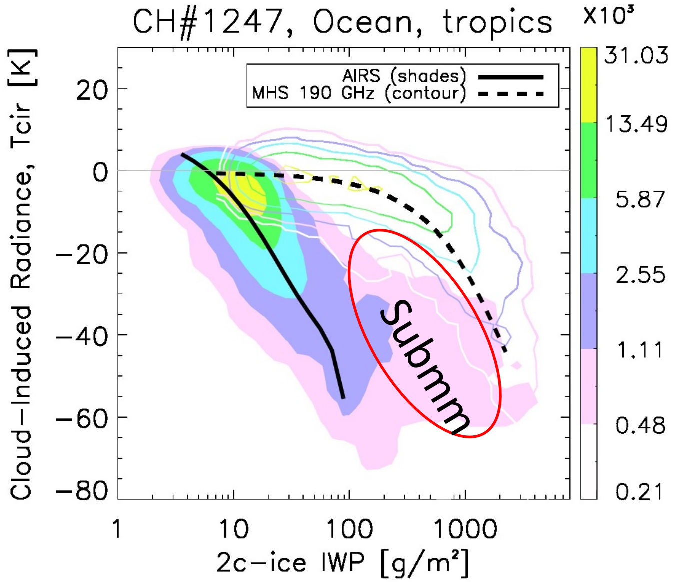
Gap in Height Coverage:

- Lack of cloud ice measurements in the mid-to-upper troposphere;
- Lack of observational constraints on ice cloud processes;

Gap in Cloud Sensitivity:

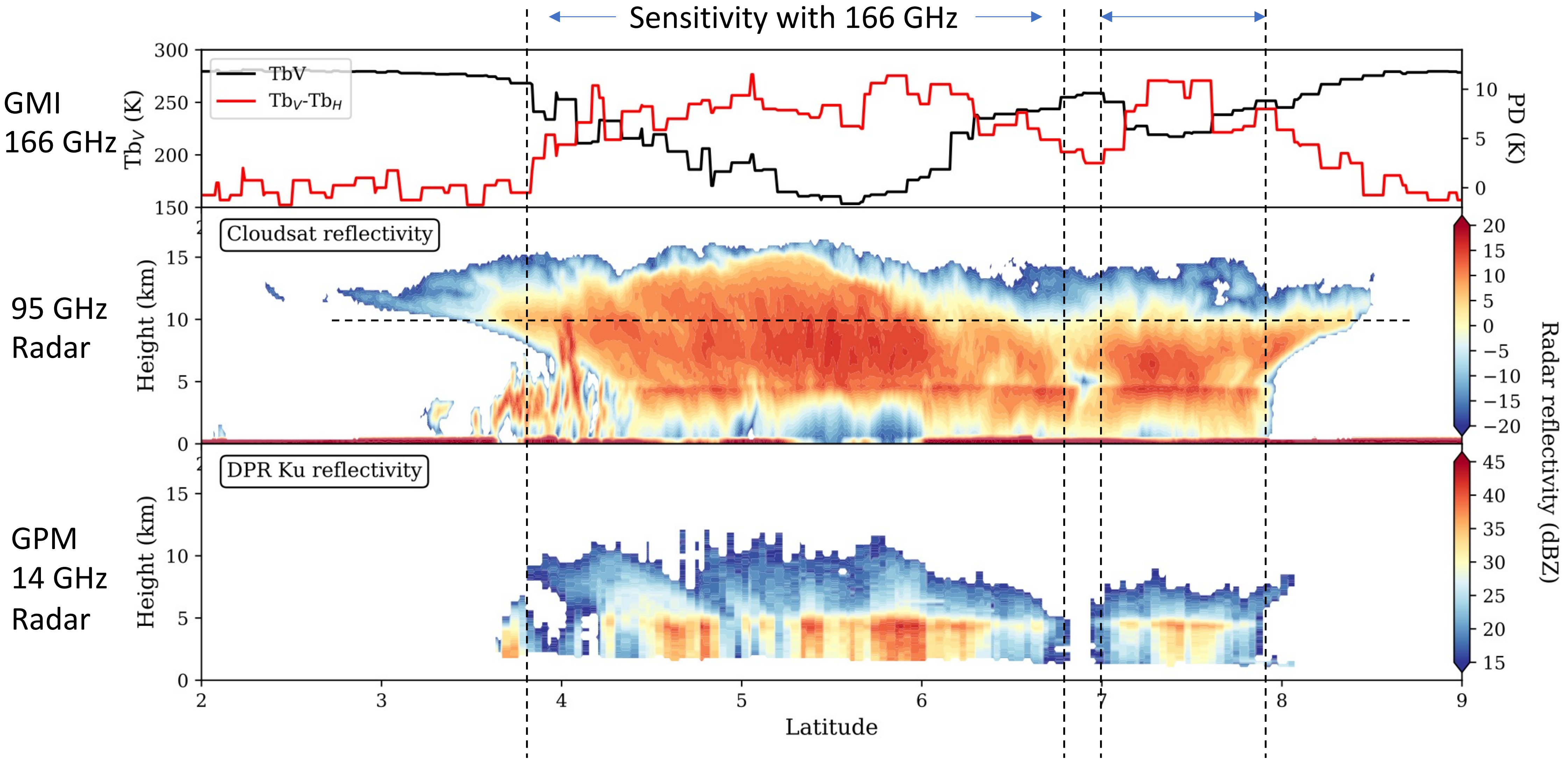
- Limitation of IR sensitivity to cloud top;
- Limitation of microwave to liquid cloud and surface precipitation;
- Submm-wave radiometer to fill the gap in cloud ice measurements;
- Polarimetric channels to measure ice particle shape and orientation.





(Courtesy of J. Gong)

GPM (GMI/166 GHz and Ku Radar) and CloudSat

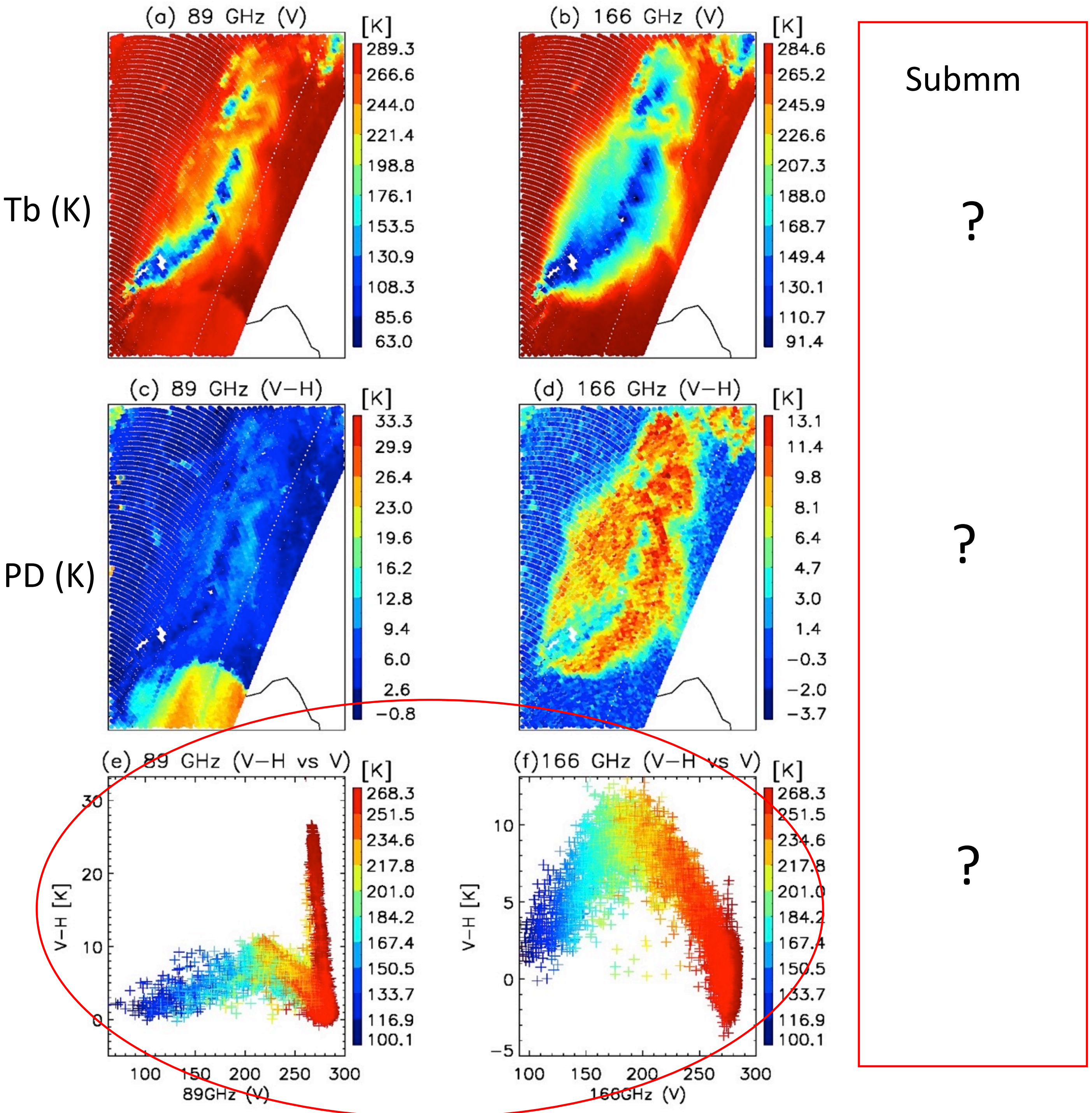


(Padulles et al., 2021)

Polarimetric Difference In GMI 89 and 166 GHz Radiances

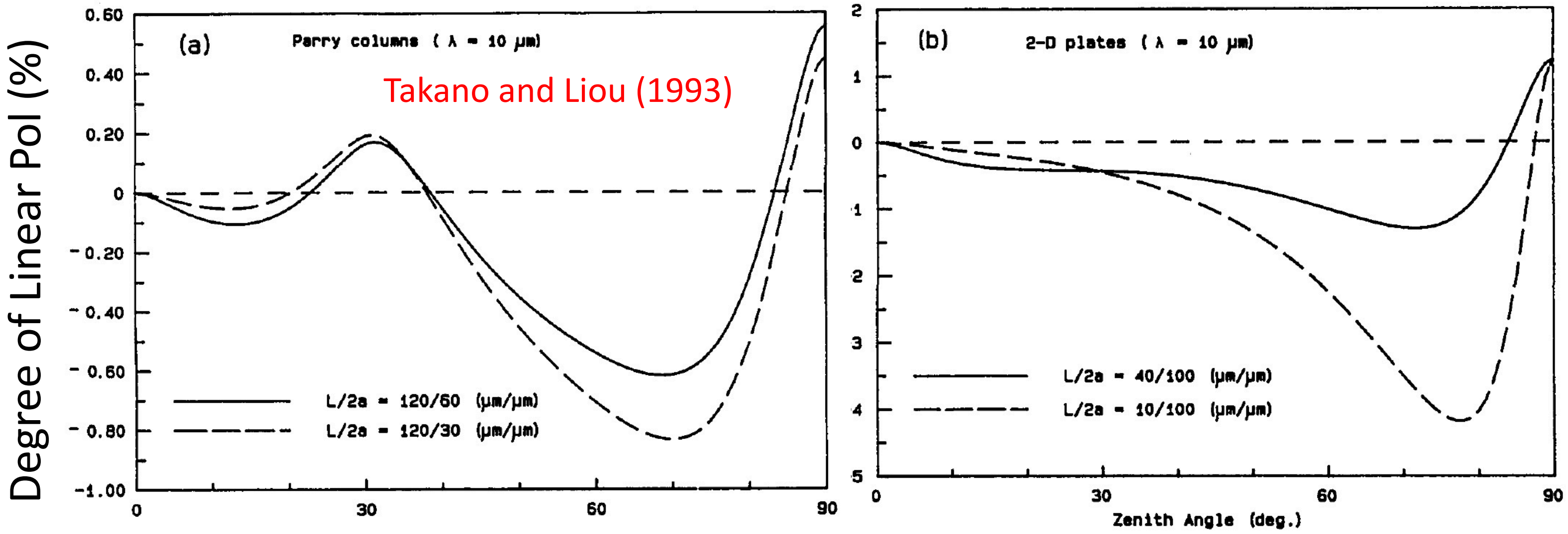
- "Bell-Shape" in the TB vs V-H relationship from cloud ice
- Larger V-H in the leading edge of squall line storms
- Similar magnitudes (~10 K) of V-H at 89 and 166 GHz
- V-H differences account for 10-30% cloud scattering signals at TB=200-270K
- Stronger ocean surface polarization contributions at 89 GHz, compared to 166 GHz

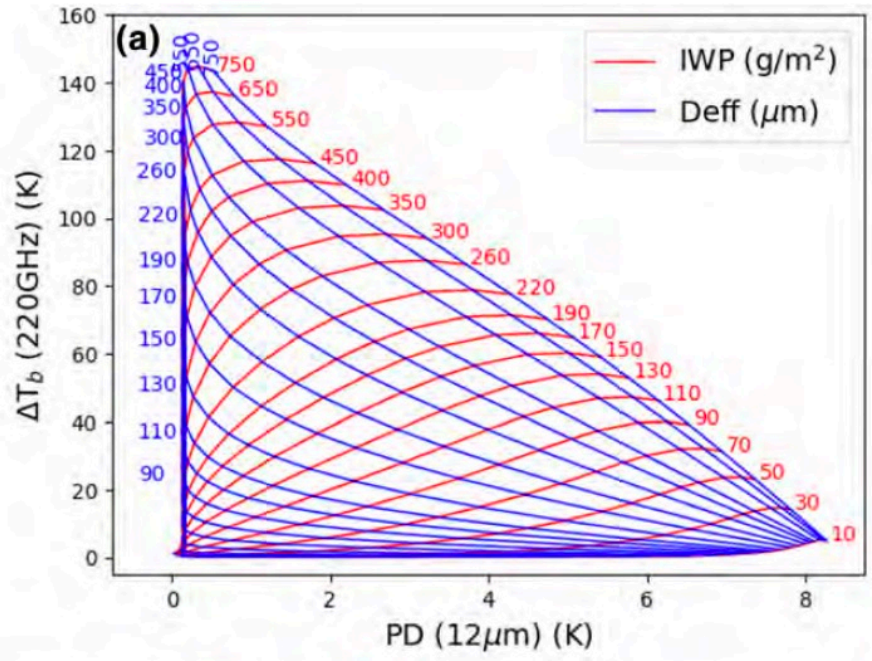
Gong and Wu (2017, ACP)



Polarized Cloud Radiances at IR?

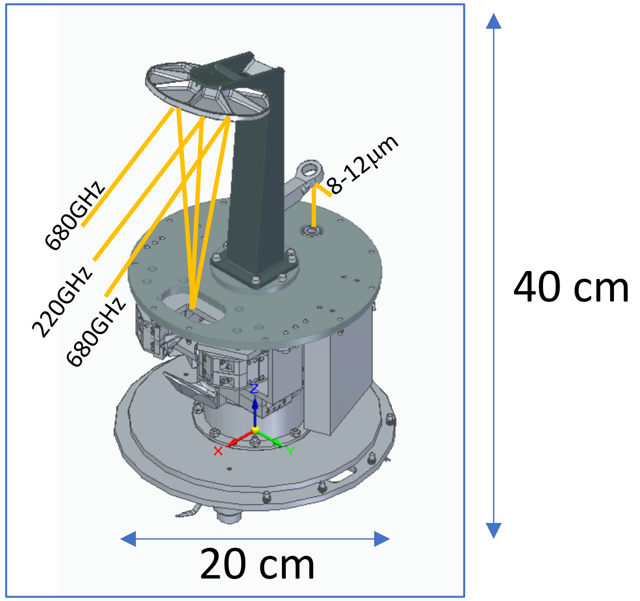
- No polarimetric IR measurements of ice cloud scattering;
- Model simulations suggest observable polarization difference (PD) radiances
- PD to provide additional information on cirrus ice particle shape/orientation

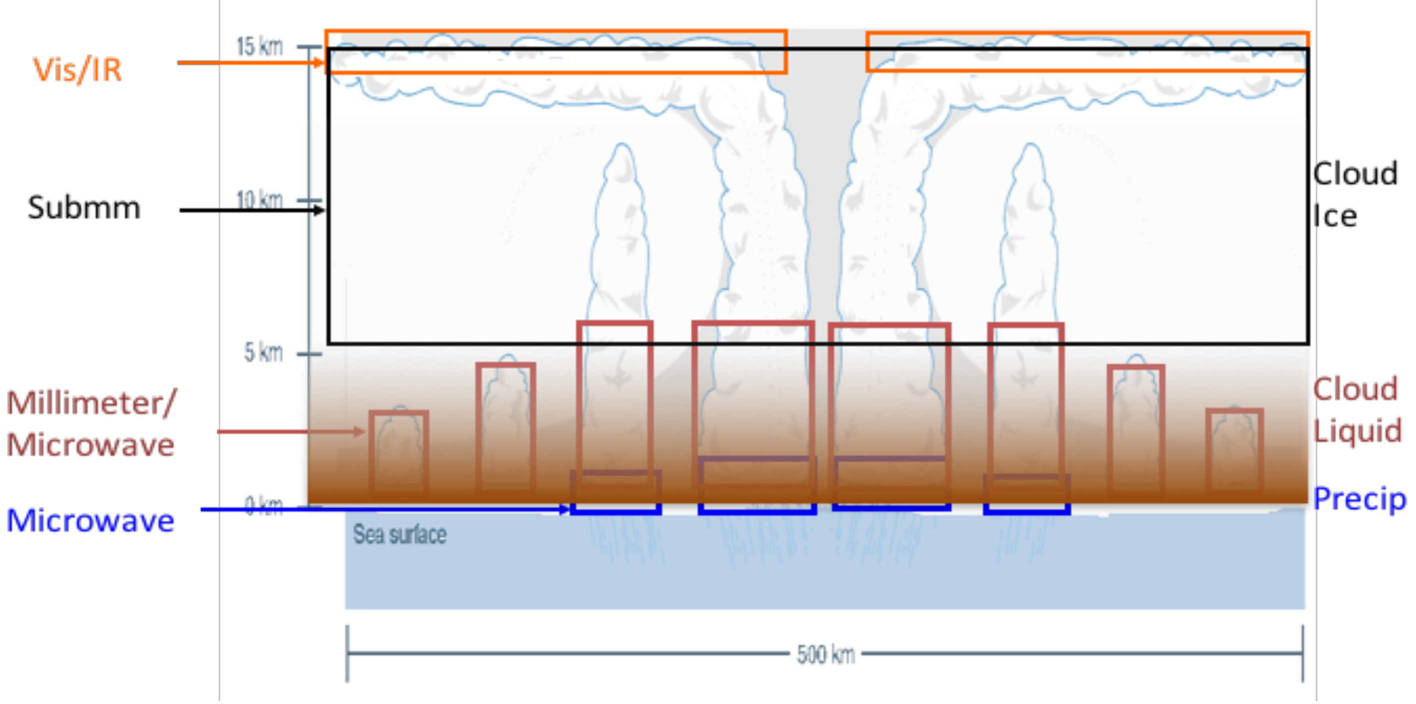




Coy et al. (2020)

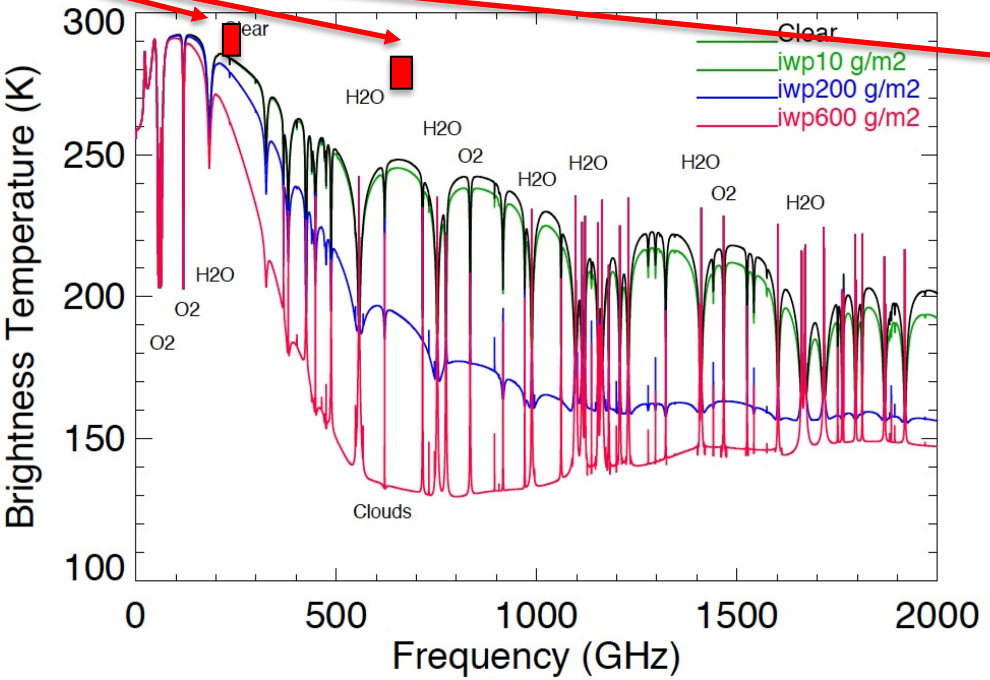
- Simulations from Atmospheric Radiative Transfer Model (ARTS)
- Optically thin cirrus layer (9-11 km)
- Roughened hexagonal 8-column aggregates with random orientation

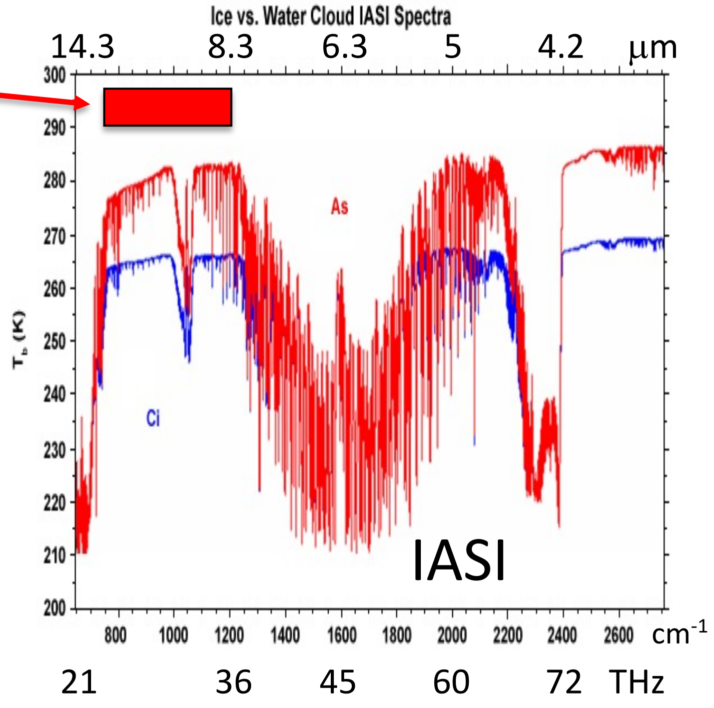


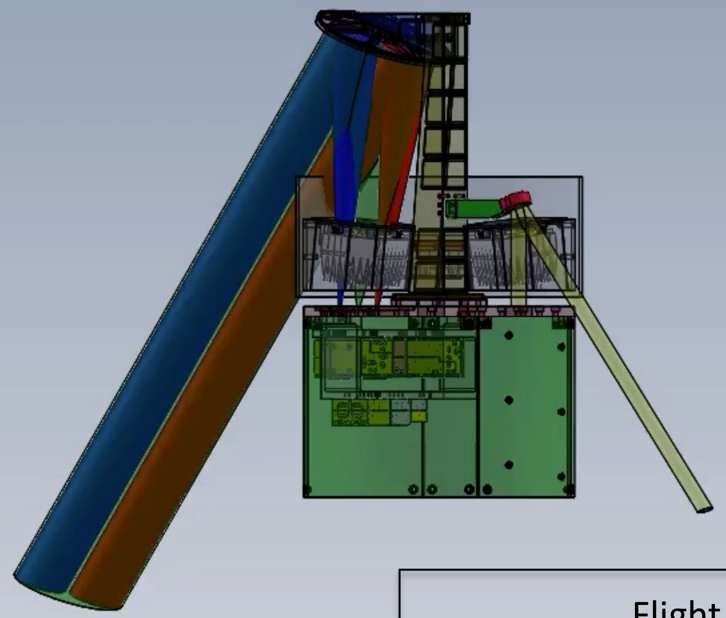


Submm-Wave and IR Polarimeters (SWIRP)

220 GHz
680 GHz
8-12 μm

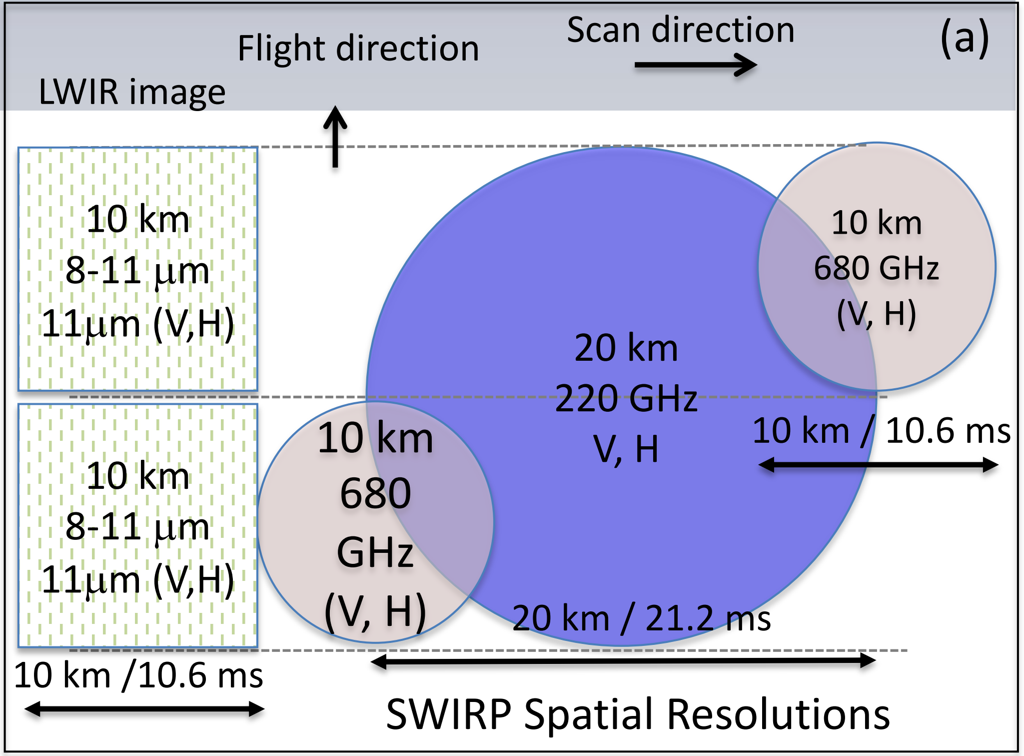


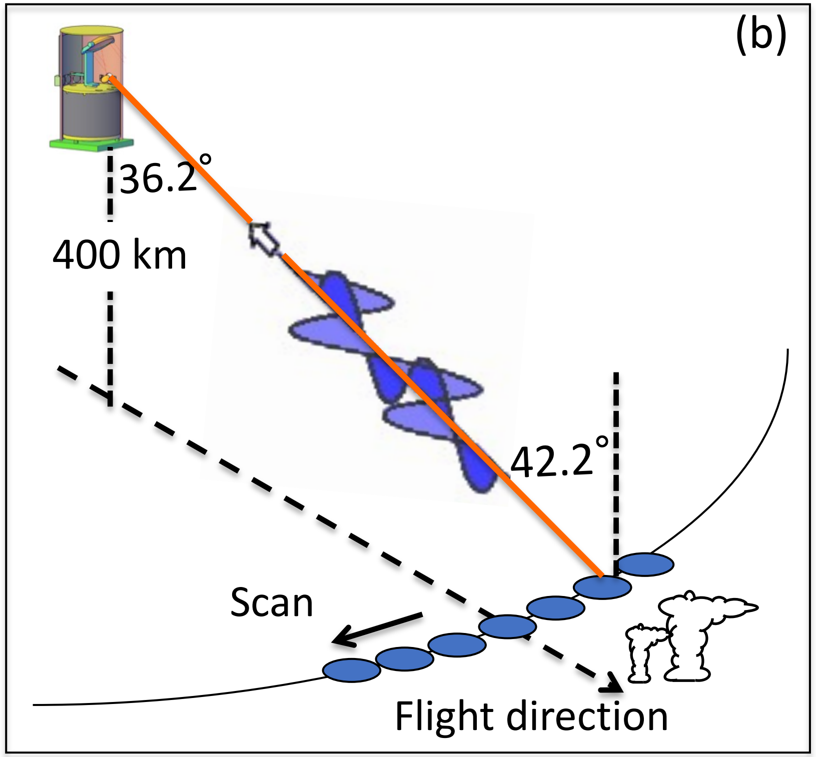




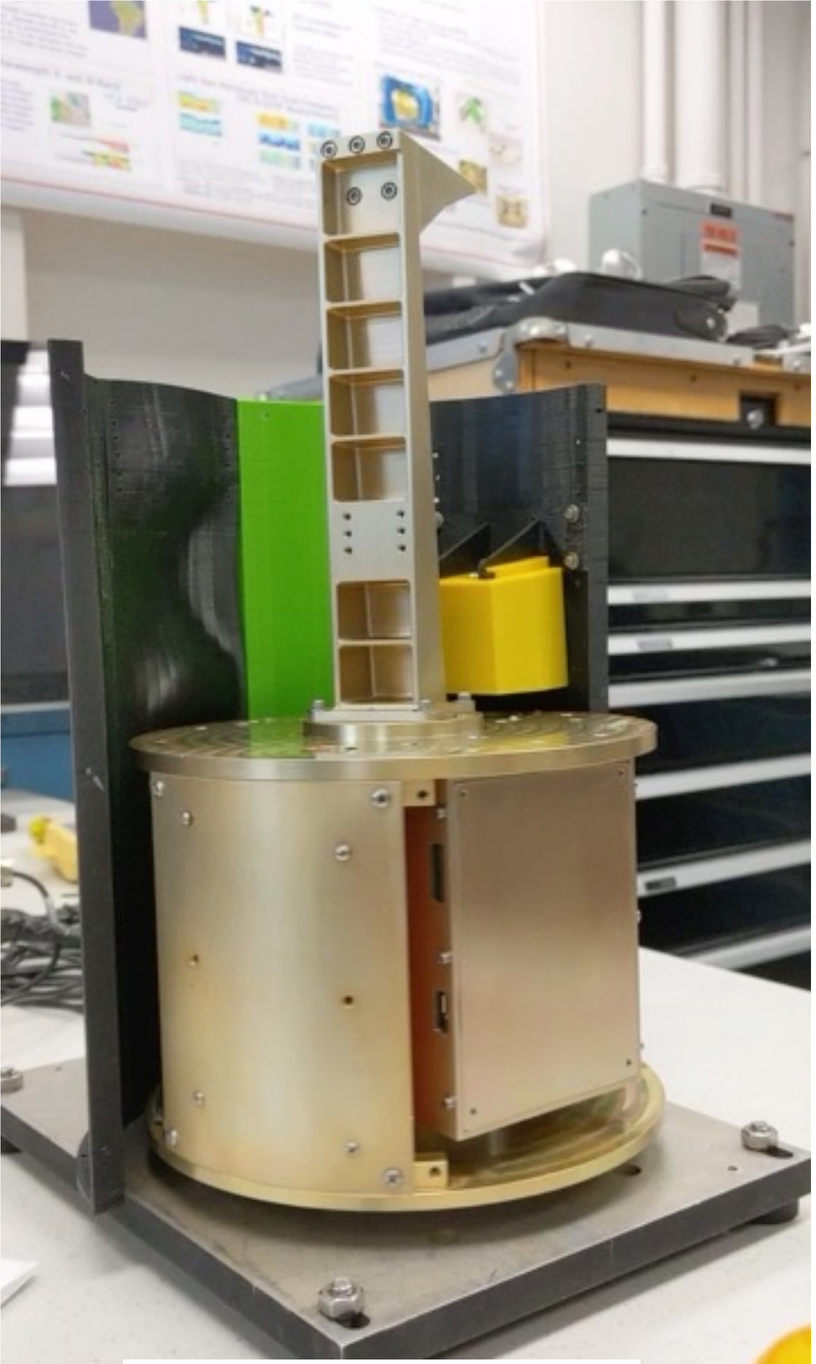
SWIRP Parameters and Requirements

- Flight altitude 400km; Swath 700 km
- Conical scan rate: 17.6 rpm
- Integration time: 21.2 ms (220 GHz), 10.6 ms (680 GHz), 10.6 ms (11 μm)
- Submm primary reflector 3dB diameter : 6.7 cm
- Footprints/FOVs: 220 GHz (20 km /1.6°), : 680 GHz (10 km /0.8°), 11 μm (10 km/0.8°)
- Submm polarimetric receivers:
  - 680 GHz (V, H), 2x: direct detection (baseline)
  - 220 GHz (V, H), 1x direct detection
- LWIR polarimeter:
  - 8-11μm channeled spectropolarimeter
- Data rate: 22.3 kbps



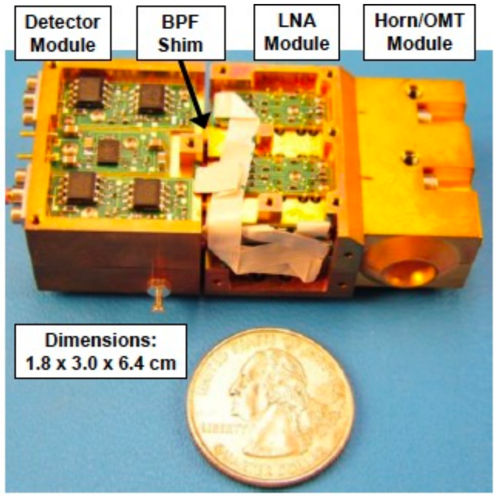


SWIRP Development

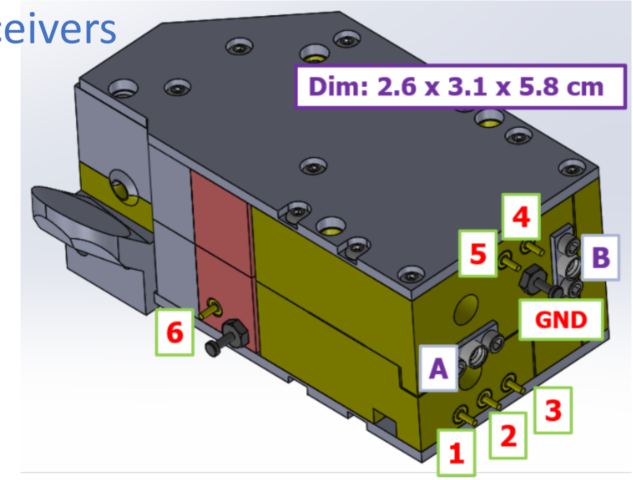


(Courtesy of P. Pantina)

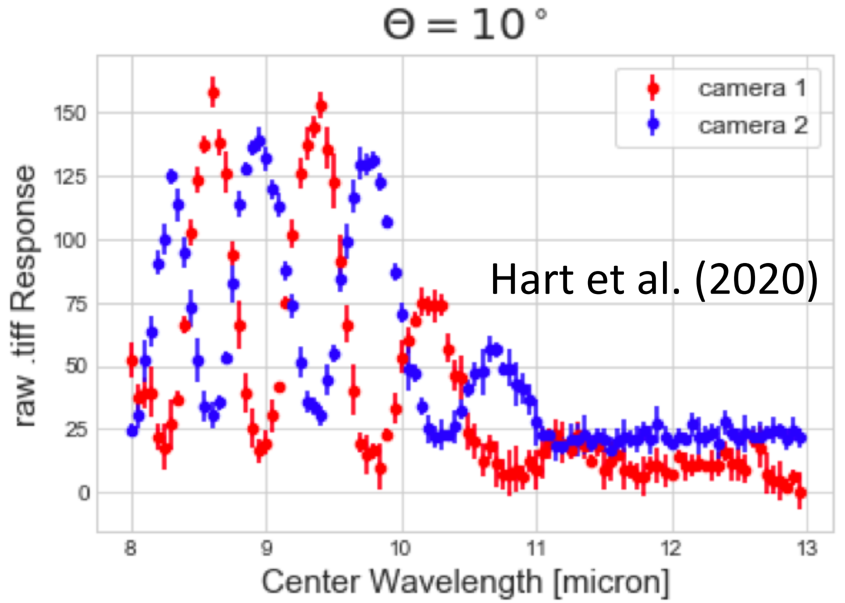
220 GHz Receiver (Cooke et al. 2019)



2x 680 GHz Receivers

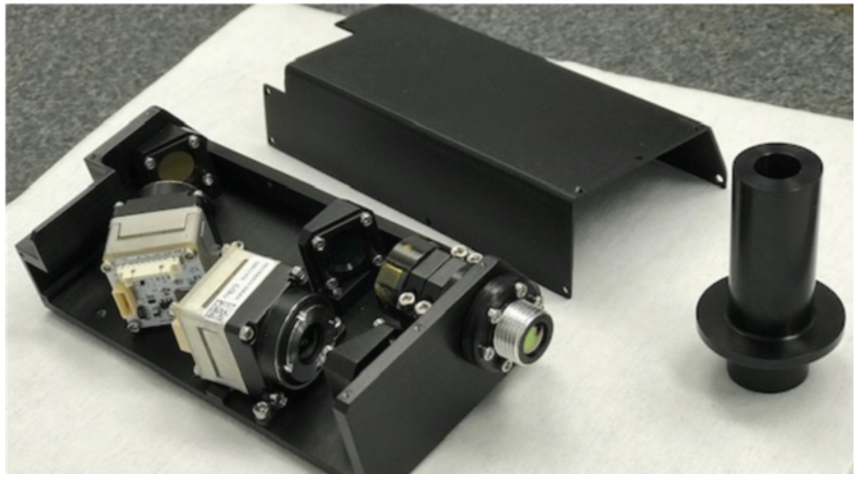


Submm Polarimetric Receivers from NGC
(W. Dell, C. Cooke)



Hart et al. (2020)

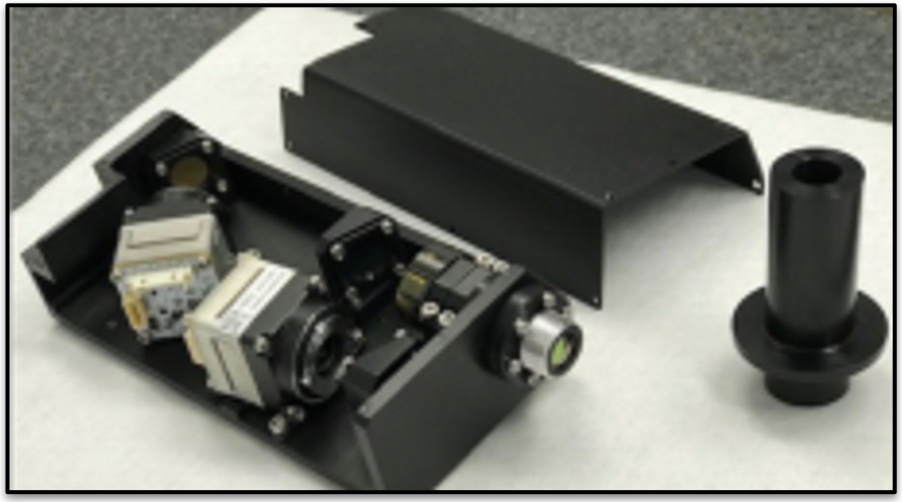
IR Channeled-SpectroPolarimeter (IRCSP) from Univ of Arizona
(R. Chipman, K. Hart, M. Kupinski, C-J Oh)



Calibration and Near Space Deployment of LWIR Channeled Spectro-Polarimeter

- ❖ The Polarization Lab, in collaboration with a team at NASA Goddard Flight Center, has developed the Infrared Channeled Spectro-Polarimeter (IRCSP).
- ❖ A novel instrument designed to collect polarimetric data of thermal radiation from ice crystals in cirrus clouds as part of a CubeSat payload
- ❖ A clone instrument was constructed in 2020 for testing at UA and support of instrument at GSFC
- ❖ In person work is being done to test and optimize calibration and polarimetric retrievals for broadband LWIR radiation
- ❖ Successful 2020 FINESST proposal is supporting work to adapt clone instrument for a piggyback high altitude balloon flight through CSBF

Assembled IRCSP Instrument



Kira A. Hart, Meredith K. Kupinski, Dong L. Wu, Russell A. Chipman, "First results from an uncooled LWIR polarimeter for cubesat deployment," Opt. Eng. 59(7) 075103 (3 July 2020) https://doi.org/10.1117/1.OE.59.7.075103

University of Arizona Team

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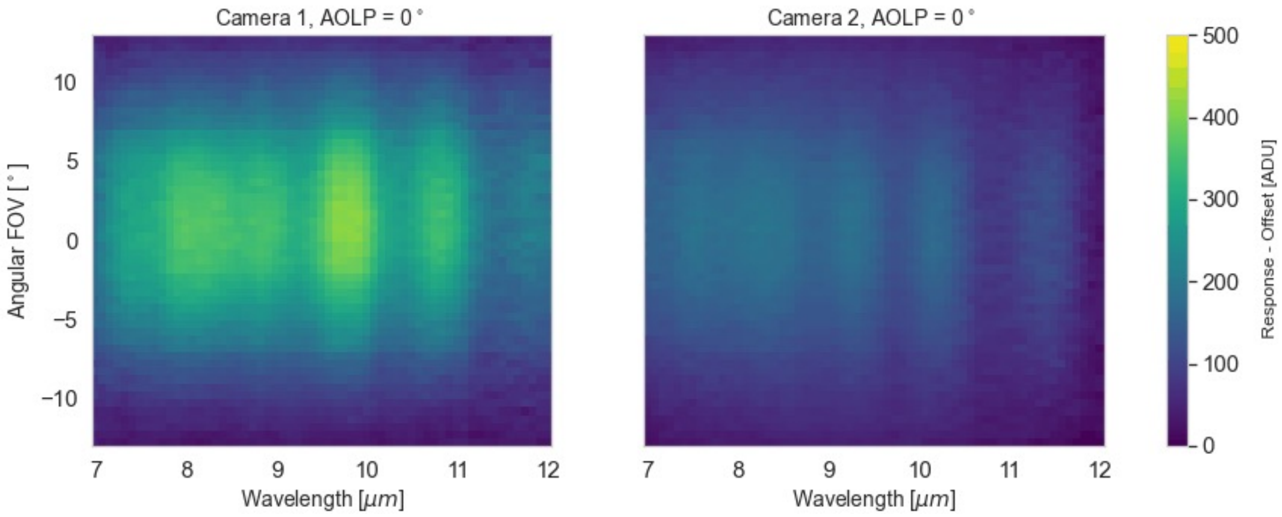
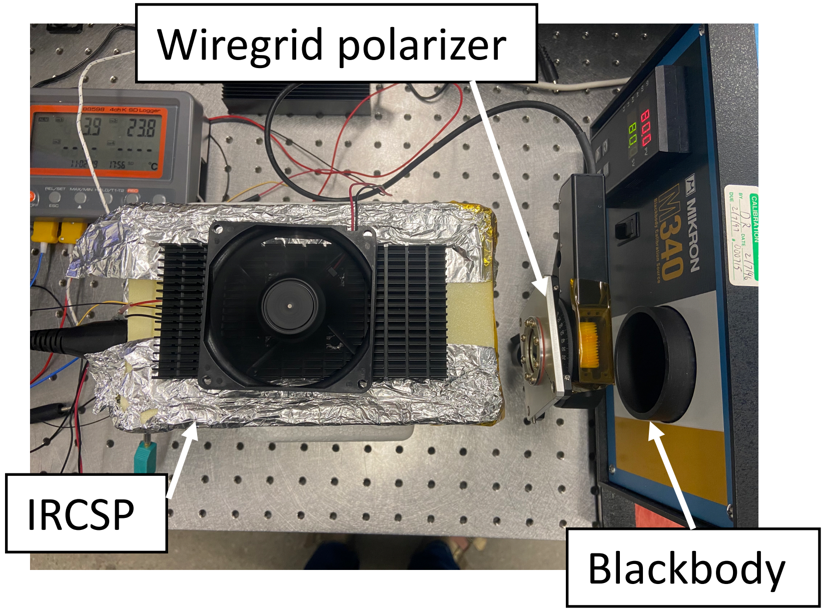
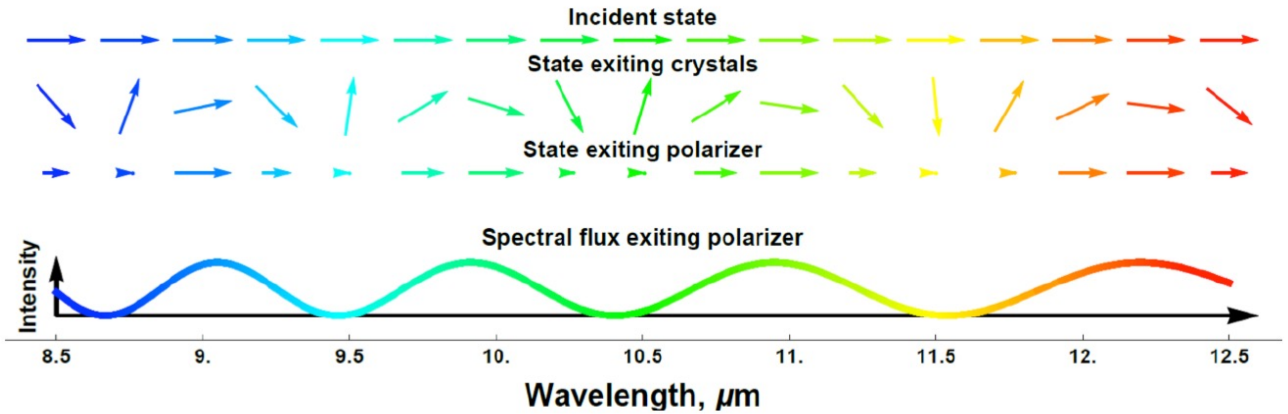
Broadband Polarized Characterization and Calibration







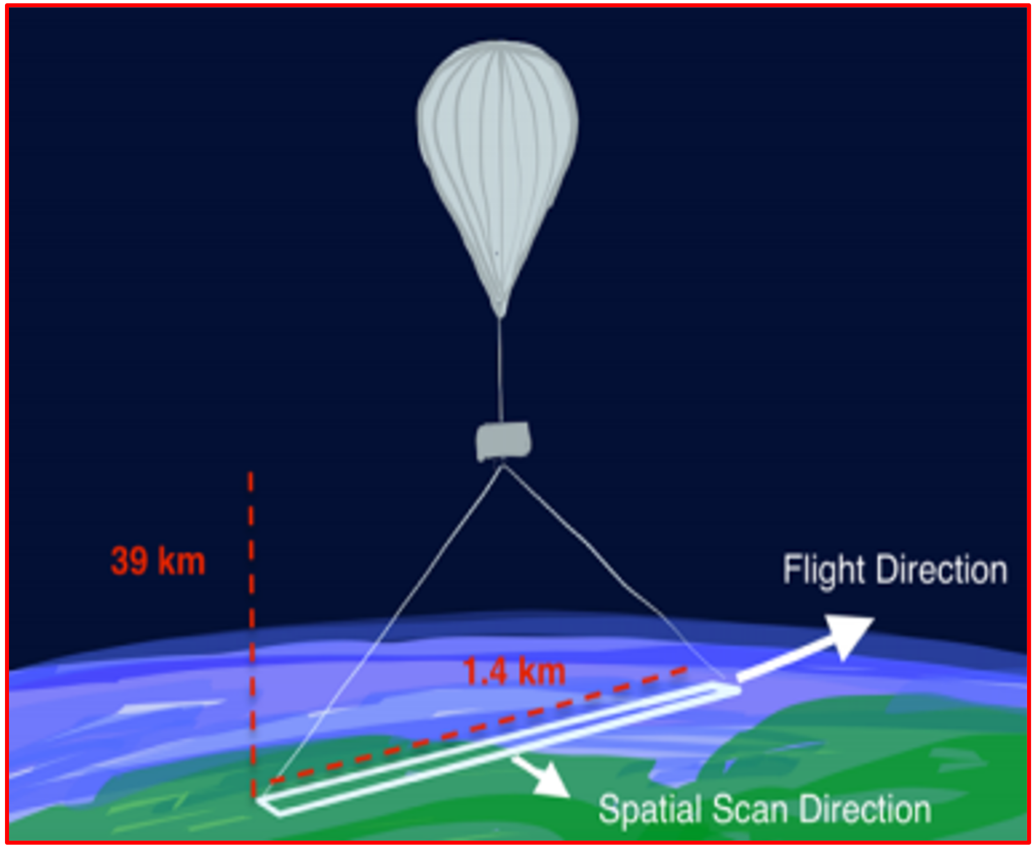
- Large aperture wire grid polarizer is rotated in front of blackbody target
- As AOLP varies, the fringes at the focal plane shift
- Current work focused on fully characterizing and calibrating out instrumental polarization and stray thermal radiation

Motivation for High Altitude Balloon Flight

- ❖ In support of the greater SWIRP project, UofA is moving forward with a high-altitude piggyback flight as proposed in the 2020 FINESST award

- ❖ Confirm the instrument performance the near space environment, test response to thermal and mechanical shock

- ❖ Required the design and testing of an enclosure
  - ➢ Environmental regulation system, that protects the IRCSP.
  - ➢ Communication system of the telemetry that obtains GPS information from the balloon's consolidated instrument package (CIP).
  - ➢ Data Management System that will retrieve, parse and store data
  - ➢ Battery distribution timeline that will power subsystems throughout the flight



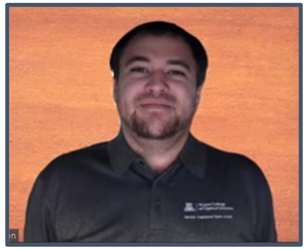
FINESST 2020 Proposal: High-altitude balloon demonstration and observations with a novel LWIR spectro-polarimeter for future CubeSat applications. *K.Hart, M. Kupinski.*

Involvement of Senior Engineering Capstone Team

- Interdisciplinary team of undergraduate students to assist in the design of the balloon payload as their senior capstone project
- Team was responsible for the design of the mechanical, thermal, and data storage for the IRCSP balloon payload
- Final project video can be found at: https://youtu.be/c5BzKVGUZ2w

Project 21008 : Design of Payload for near-space deployment of IR Optics

NAYLETH RAMIREZ
Systems Engineering



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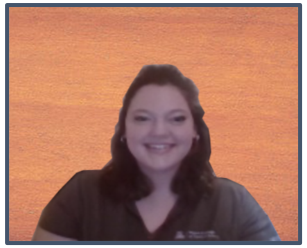

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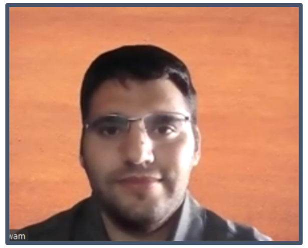
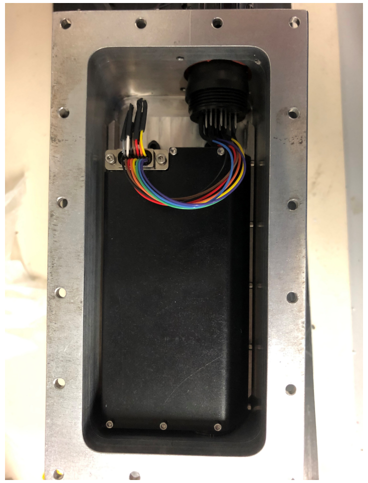
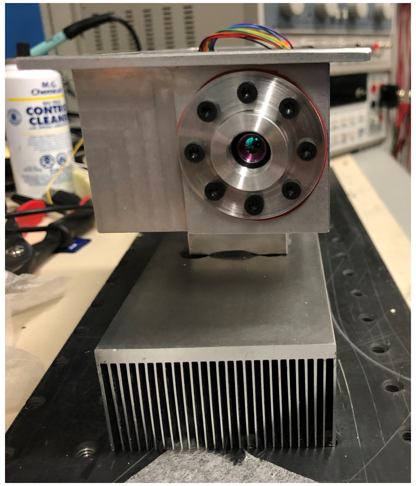
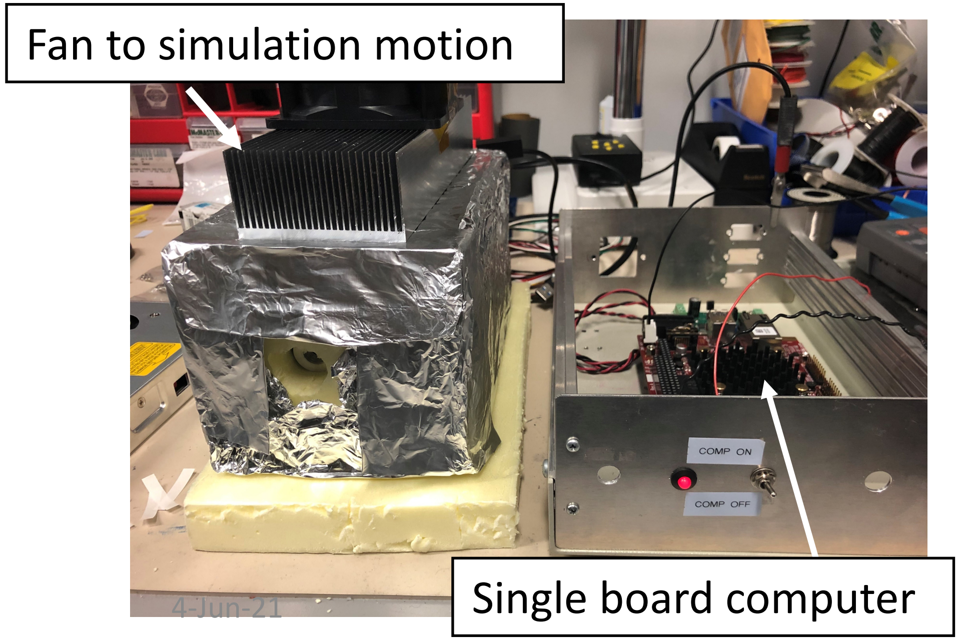


WASSIM KHAWAM
Mechanical Engineering

Installation of IRCSP in Balloon Payload







- ❖ Instrument is contained in aluminum housing with front lens of the IRCSP as the front aperture
- ❖ Thermal Electric Coolers are configured to both heat and cool the enclosure to keep the the instrument within thermal limits and prevent condensation during take-off and landing
- ❖ Single board computer controls data acquisition and storage in addition to controlling TECs and stepper motor for push broom scanning
- ❖ In lab the housing and TECs can be used to simulate performance at a variety of operating temperatures

Summary

- Ice clouds remain as a major source of uncertainties in climate models and prediction
- Lack (in sensitivity and mid-to-upper troposphere) of reliable cloud ice measurements means poor observational constraints on ice cloud processes and their radiation properties
- Compact submm-wave cloud radiometer-polarimeters such as SWIRP will fill the observation gaps and enable new sciences